Forward Proton Detection at eRHIC

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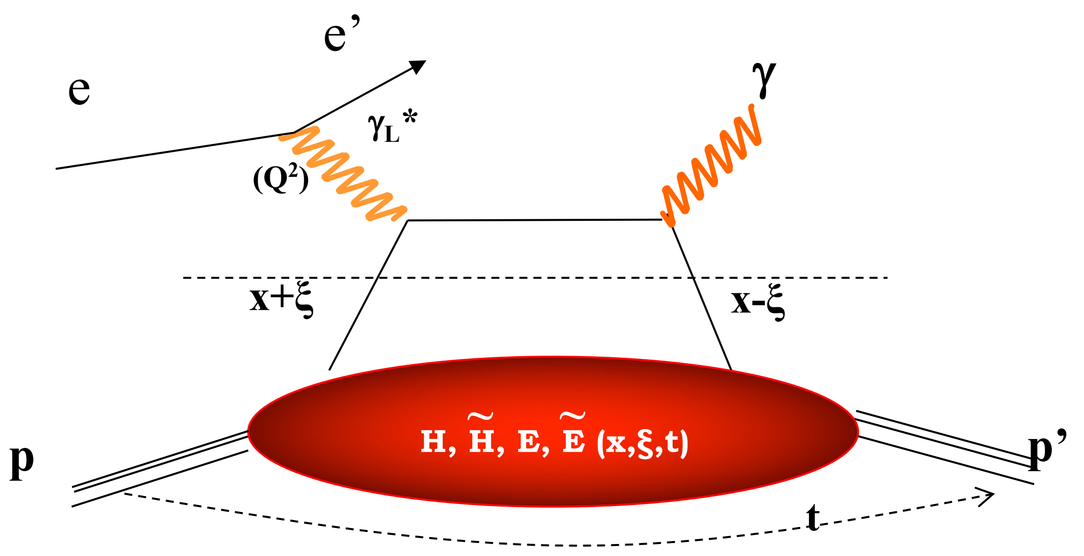
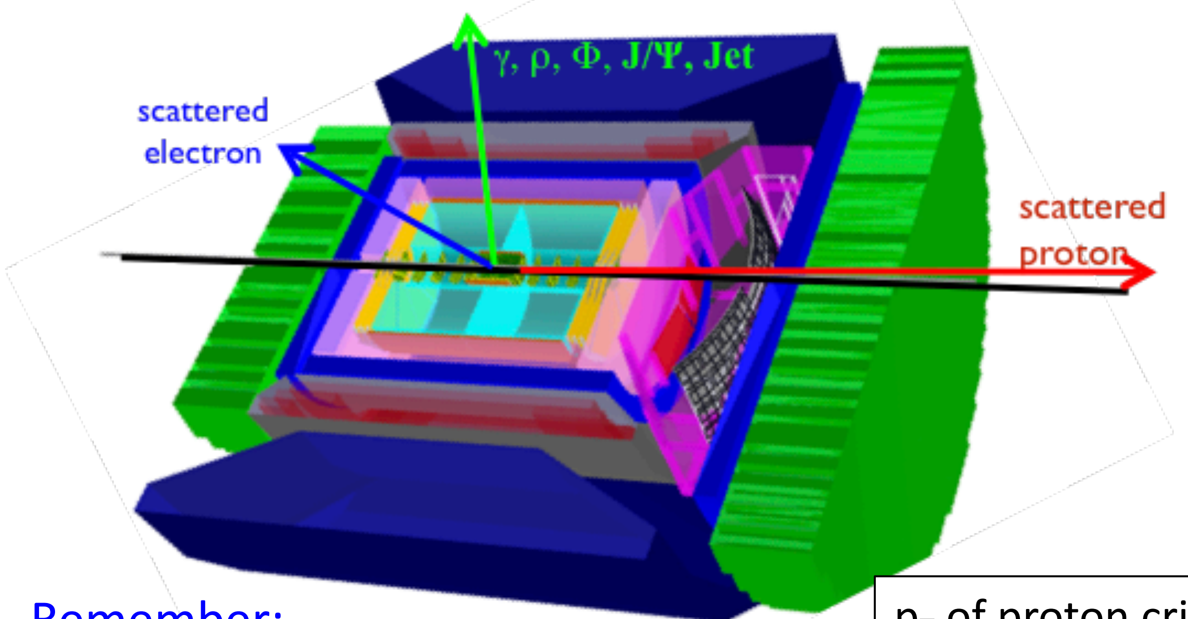
Why (very) forward proton detection?

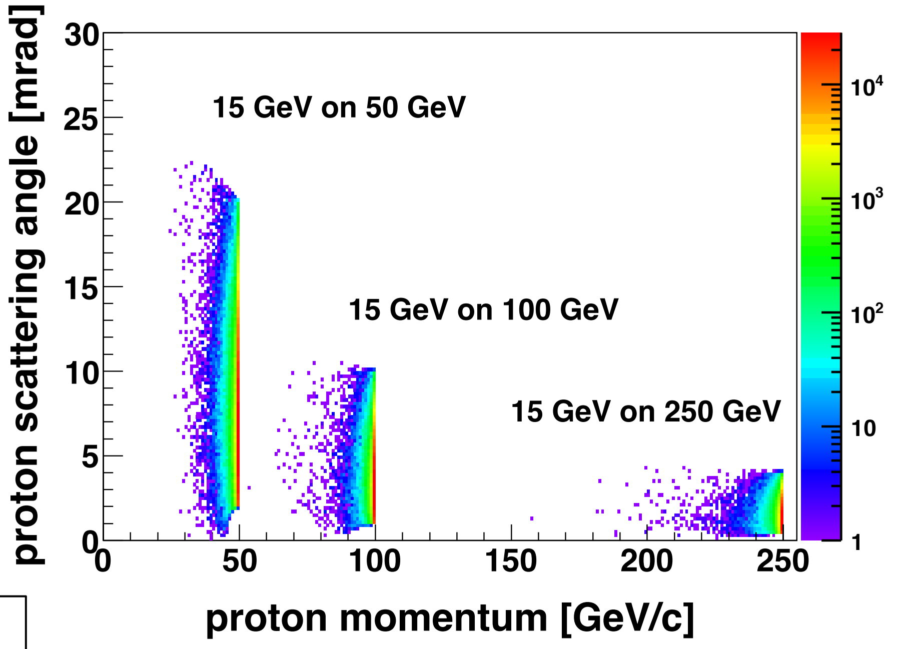
- Exclusive elastic/diffractive events (e.g. DVCS).
  - Produce very forward protons outside the acceptance of the main detector.
  - Access to information related to Generalized Parton Distributions (GPDs).
- Also useful for veto of nuclear breakup events in conjunction with ZDC for neutron detection in e+A.



Example of a DVCS event. The scattered electron and photon are measured in the main detector, and the proton with forward proton detectors.

Kinematics and Measurement "How-To"





Remember:

Detector -4 to 4 in η

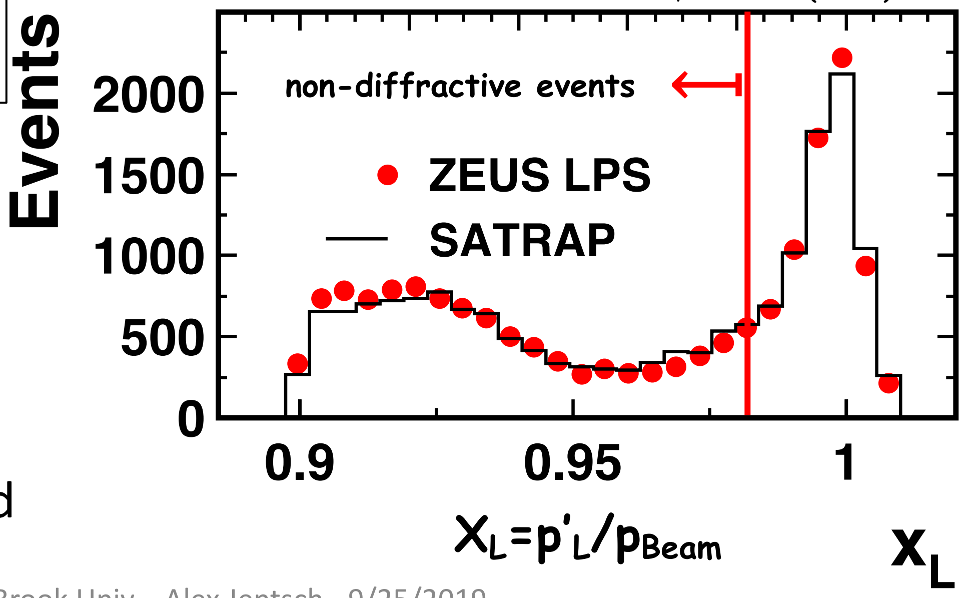
→ 35 mrad from beam line

→ so not seen in main detector

→ need different detection technology

p_T of proton critical for physics
$p_T = p' \sin\theta$
$p'_L > 97\%$ of p_{Beam}

ZEUS Coll, JHEP 06 (2009) 074

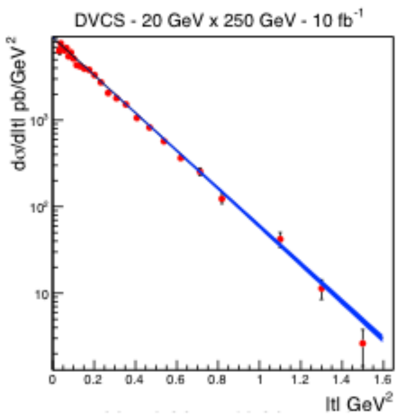


- Two-step detection process to achieve good acceptance.
  - Roman Pots at ~30 m from IP → 0 - 5 mrad
  - Silicon sensors in first dipole (B0 dipole) after IP → 5 – 25 mrad

Extracting physics information

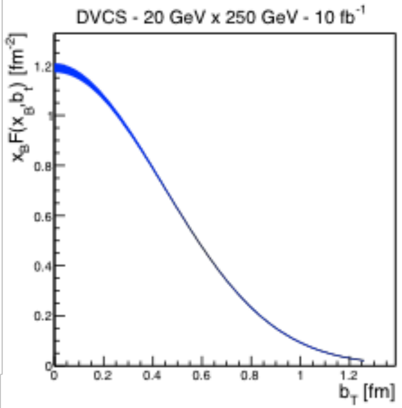
Measurement

Physics observable (Impact parameter distribution)



Plots from EIC White Paper:

Fourier transform



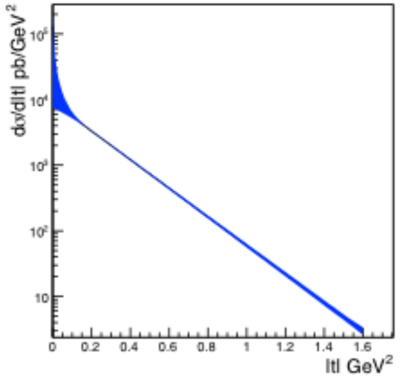
Requirement:

$\int L_{int}$=10fb^{-1}

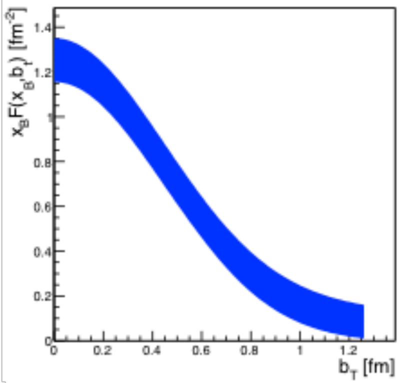
$0.18 < p_t$ (GeV) < 1.3

$0.03 < |t|$ (GeV^2)< 1.6

$$t = -(p - p')^2 \approx -p'^2_t$$



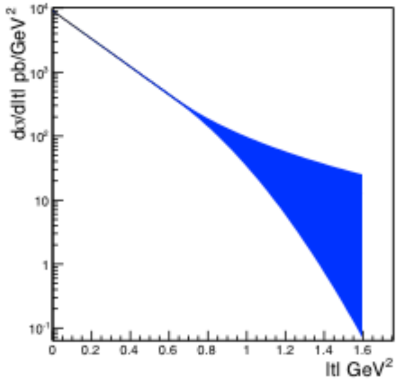
limited lower p_T-acceptance



Deficient low p_t acceptance leads to uncertainty in the normalization.

$\int L_{int}$=10fb^{-1}

$0.44 < p_T$(GeV) < 1.3



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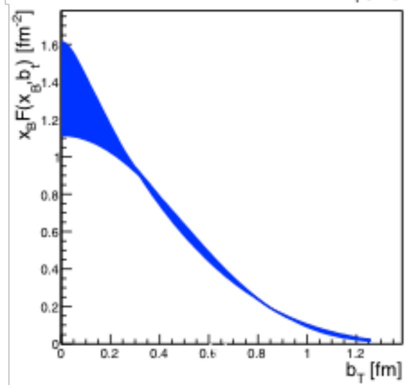


Deficient high p_t acceptance leads to uncertainty in slope extracted from |t|-dist, and a distortion of the impact parameter distribution.

$\int L_{int}$=10fb^{-1}

$0.18 < p_T$ (GeV) < 0.8

Extracting physics information

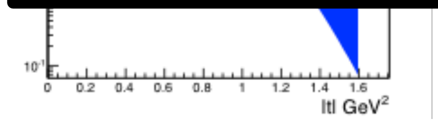
Measurement

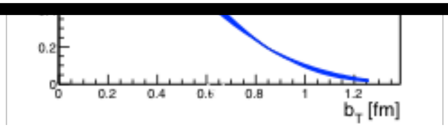
Physics observable (Impact parameter distribution)

<u>Need to accurately extract:</u>

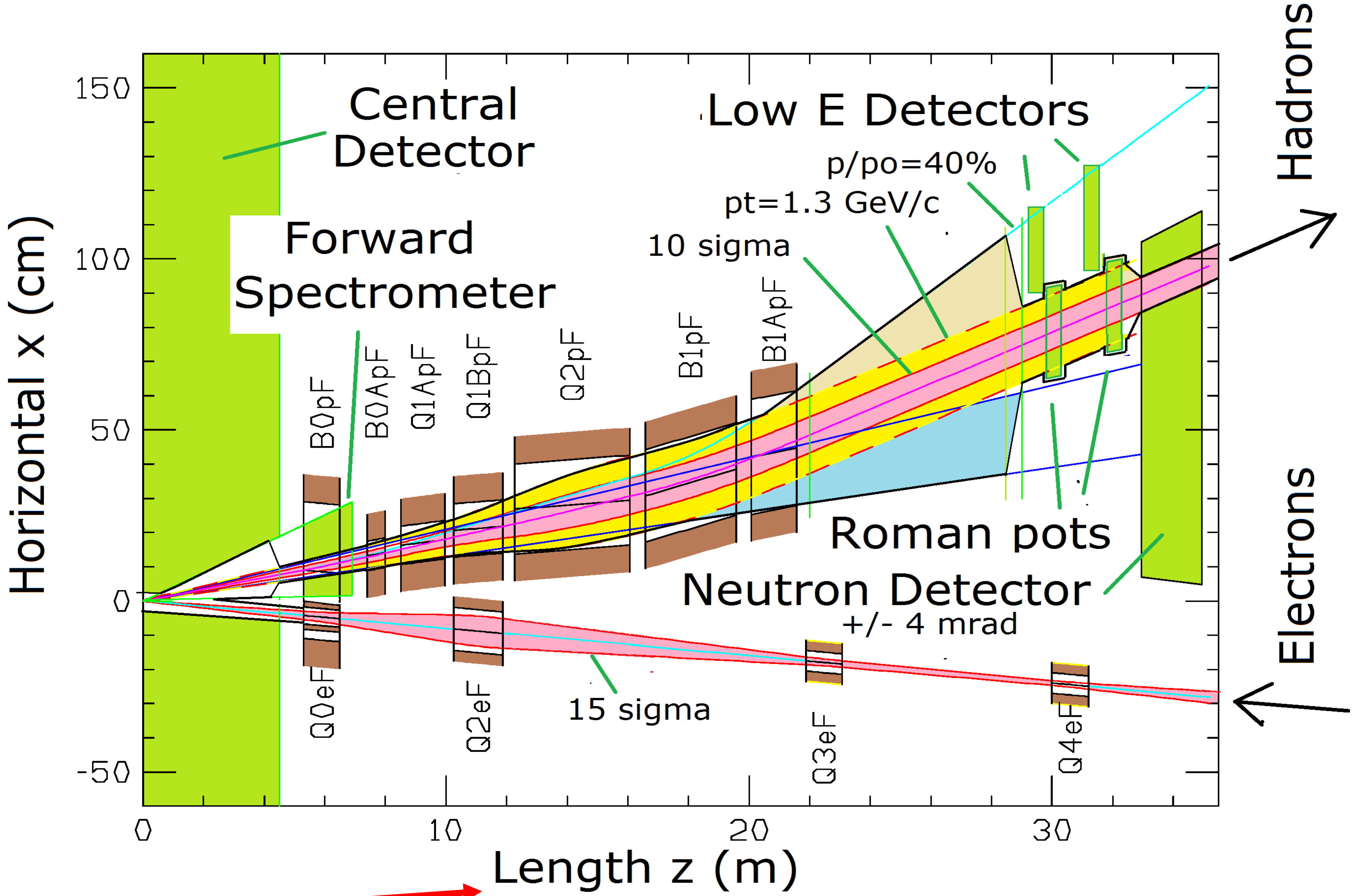
1. The functional shape of the cross section (e.g. exponential vs. dipole).
2. The slope of the cross section.

- ➢ Requires good coverage in |t|.
- ➢ Requires good resolution to limit bin migration.
- ➢ High statistics required to properly constrain the fit in the high-|t| tails.



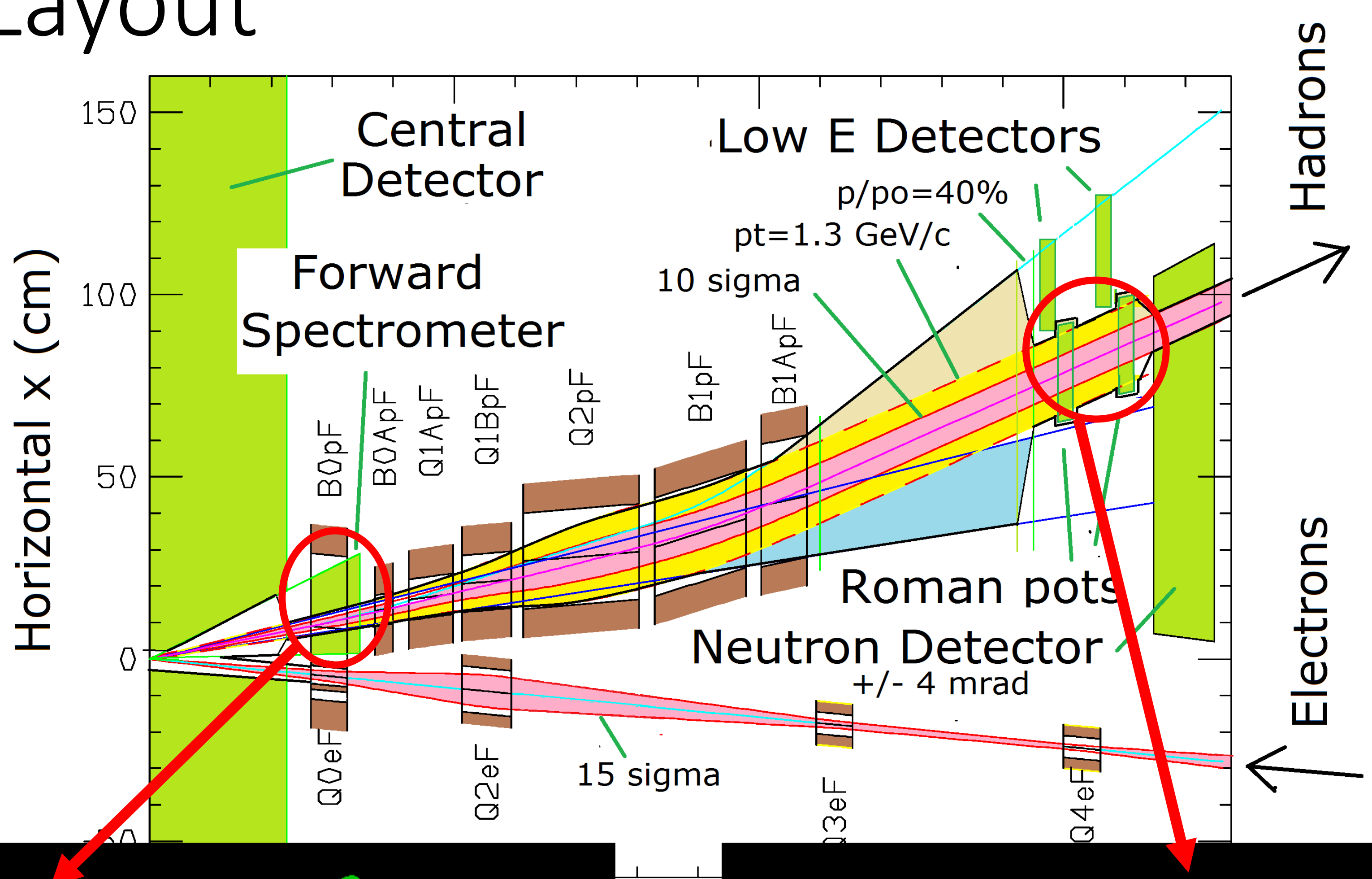


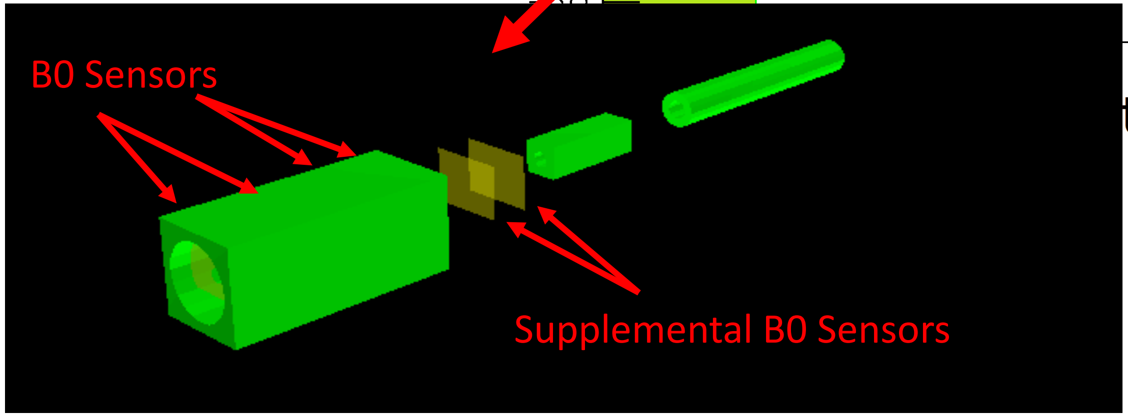
eRHIC IR Layout

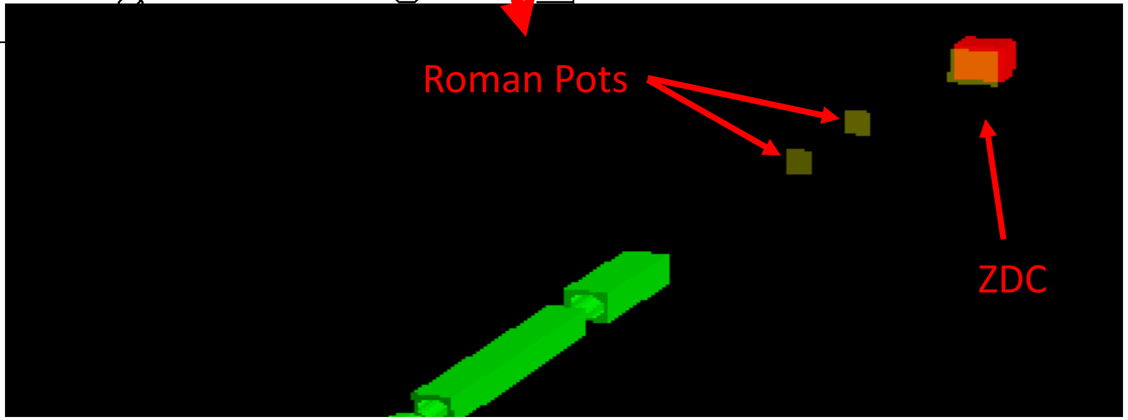


Note the different units!

eRHIC IR Layout







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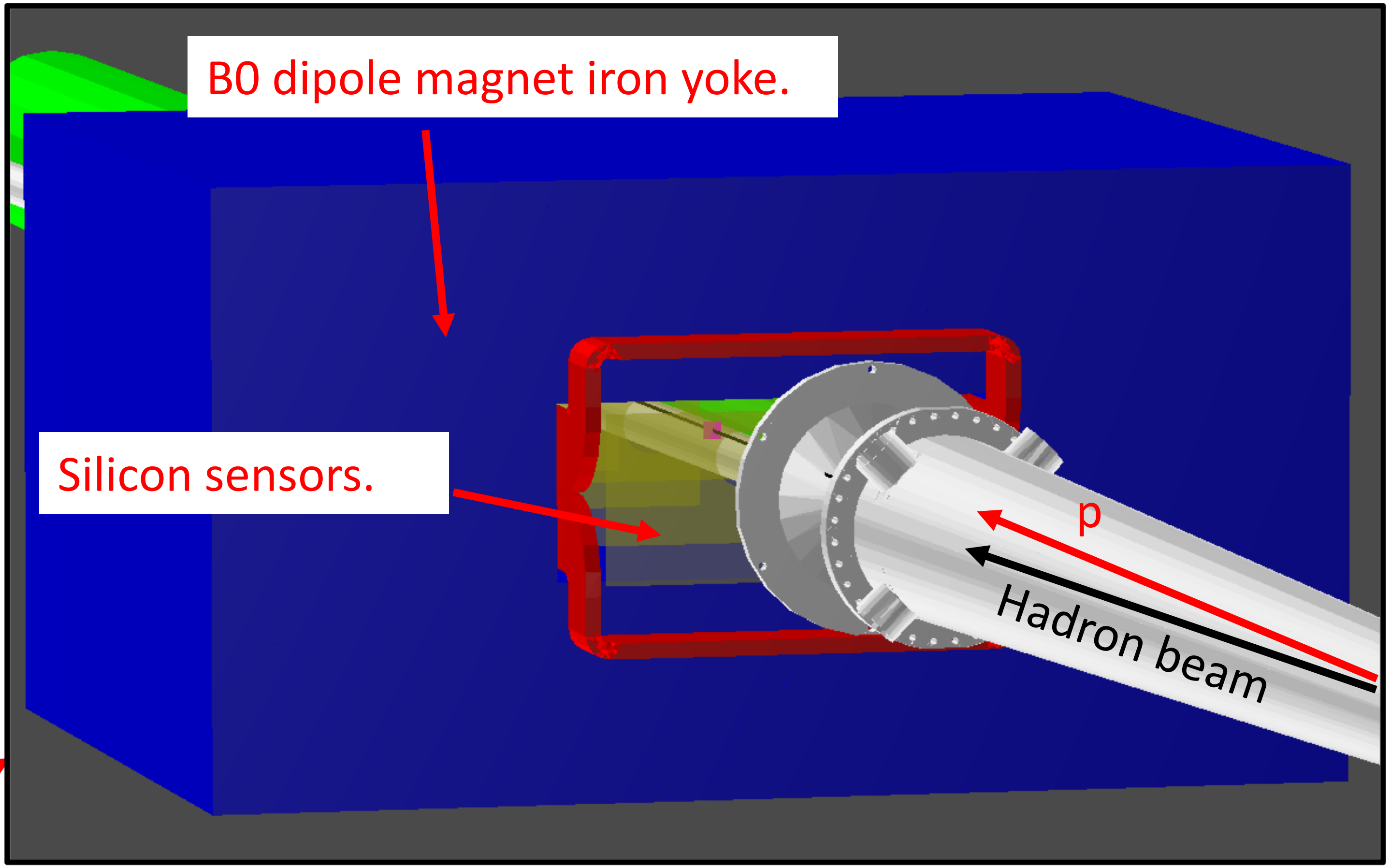

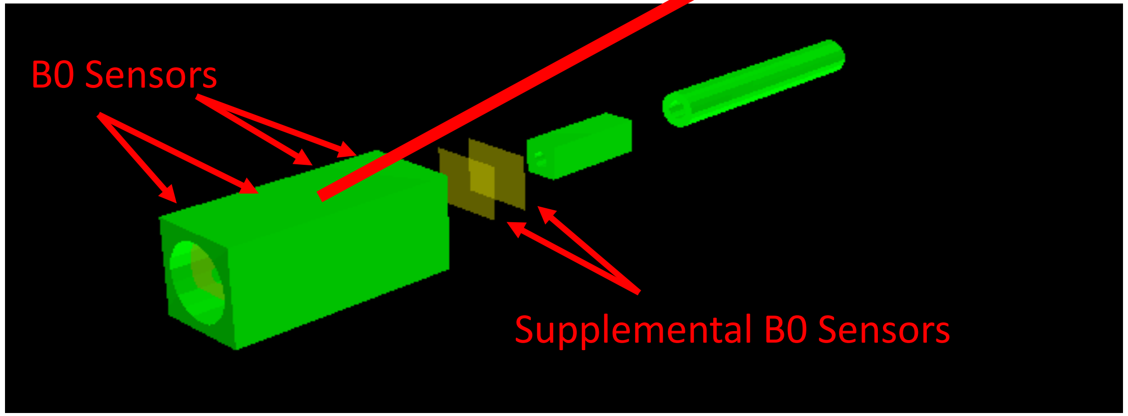

Sensors sit outside of beam pipe and detect scattered DVCS protons deflected by dipole field.

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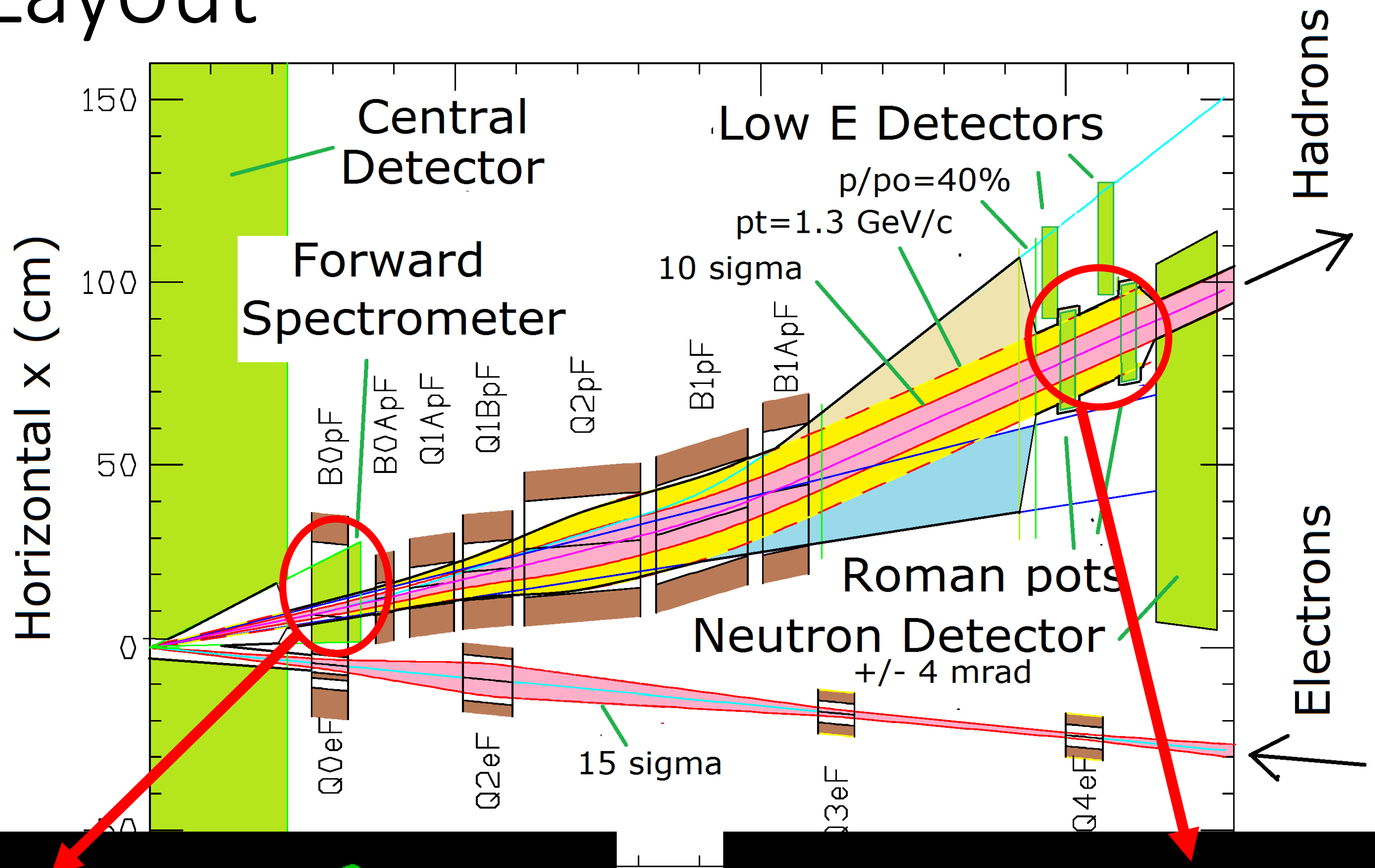
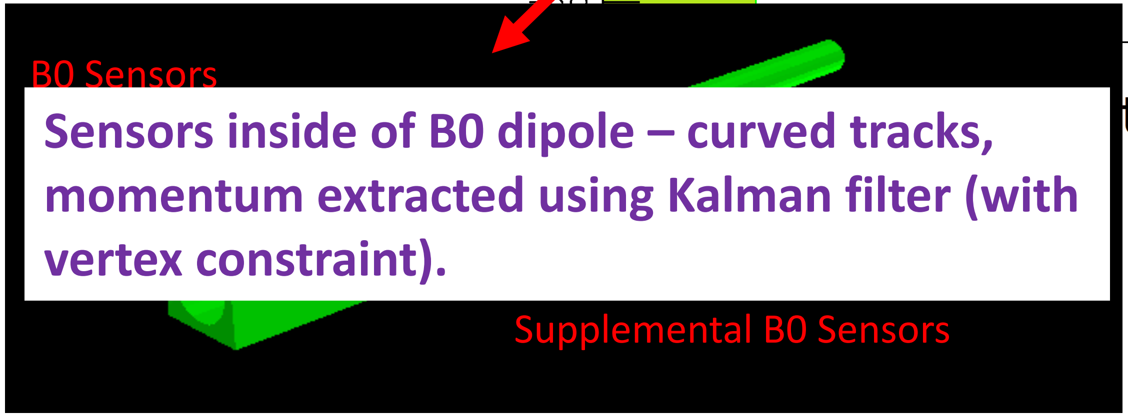
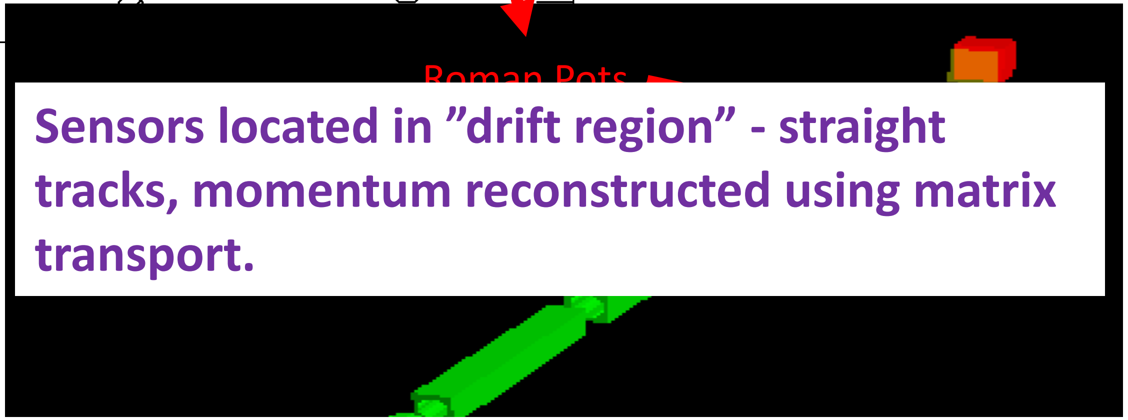




Sensors inside of B0 dipole – curved tracks, momentum extracted using Kalman filter (with vertex constraint).



Sensors located in "drift region" - straight tracks, momentum reconstructed using matrix transport.

Roman Pots with DVCS Protons

DVCS simulations

- Simulations generated using MILOU [1].
- Machine detector simulations using GEANT/eicRoot.
  - All magnets in the hadron forward going direction.
  - Silicon sensors in B0 and Roman Pots (material shape and thickness, pixel size, etc.)
- Samples generated for three beam energies.
  - 18(e)x275(p) GeV
  - 10(e)x100(p) GeV
  - 5(e)x41(p) GeV
- Sampled cross section with exponential shape and slope = 5.6 (slope chosen from HERA DVCS data).

[1] "MILOU: a Monte-Carlo for Deeply Virtual Compton Scattering", E. Perez, L. Schoeffel and L. Favart, hep-ph/0411389v1

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- Sampled cross section with exponential shape and slope = 5.6 (slope chosen from HERA DVCS data).
- Note: the simulations were run with two different configurations from the accelerator group (except 41 GeV) – one to maximize luminosity (high divergence), one to maximize acceptance (high acceptance).

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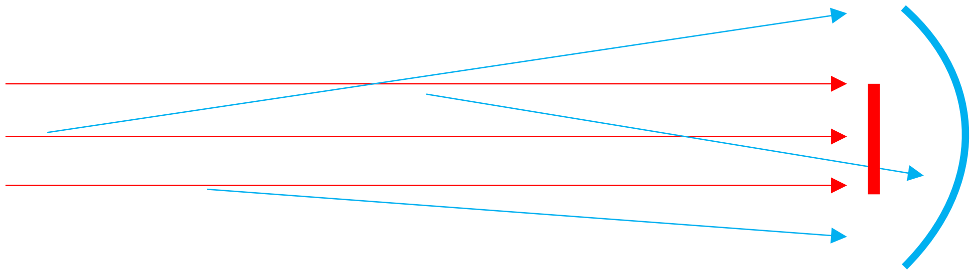
Short Diversion – Accelerator Jargon

- Angular divergence
  - Angular “spread” of the beam away from the central trajectory.
  - Gives some small initial transverse momentum to the beam particles.



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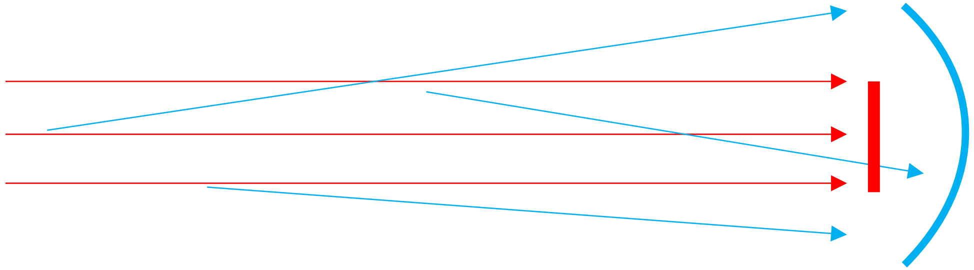
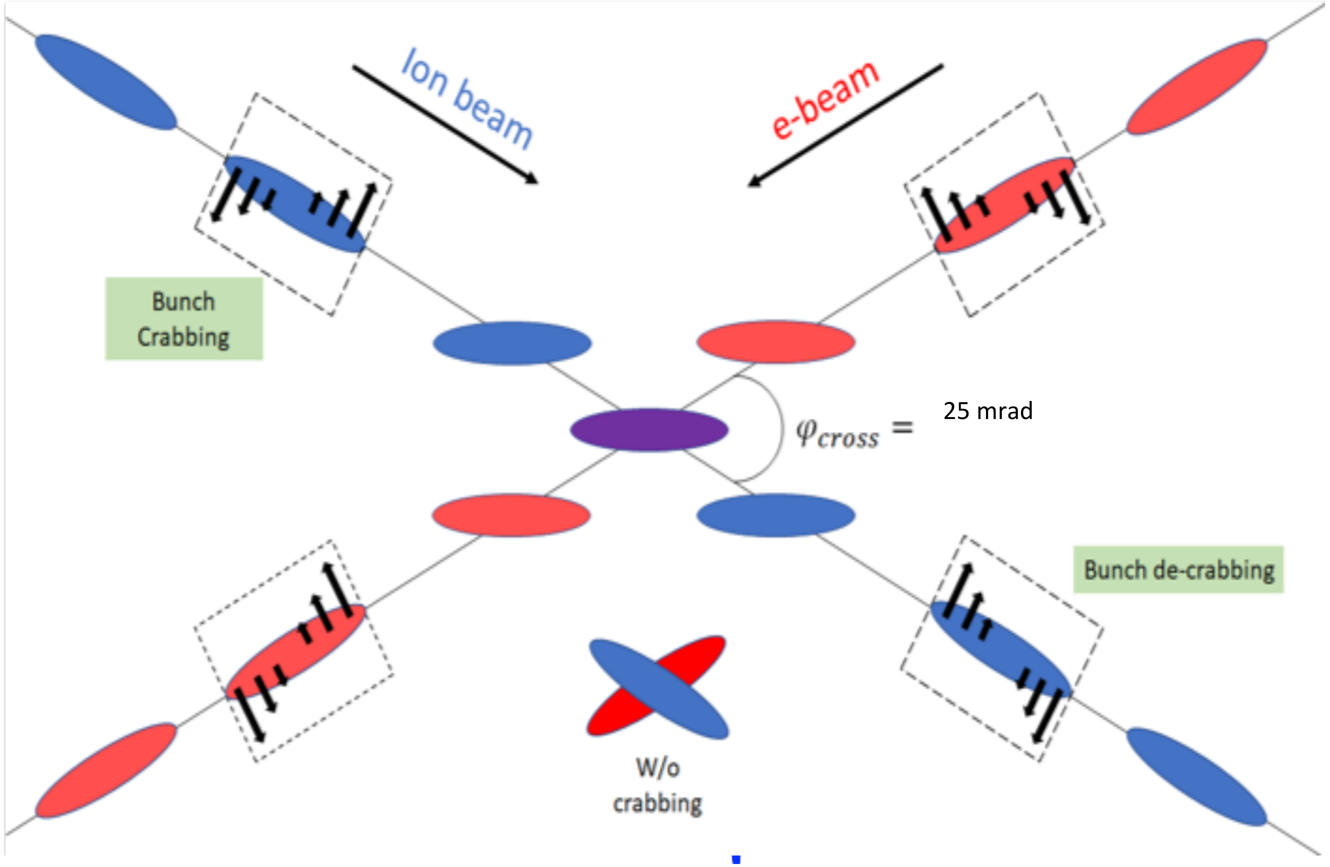
- Crab cavity
  - Can perform rotations of the beam bunches in 2D.
  - Used to account for the luminosity drop due to the crossing angle – allows for head-on collisions to still take place.





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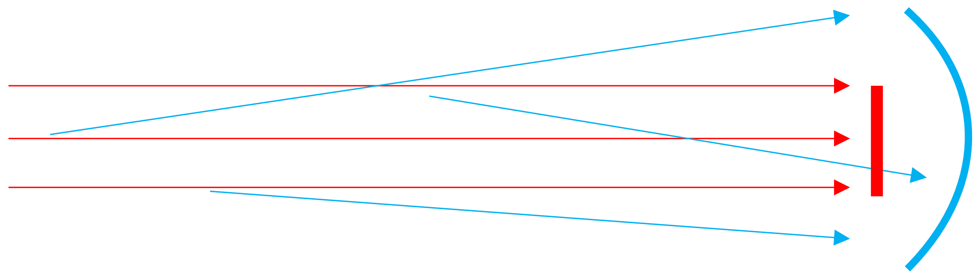

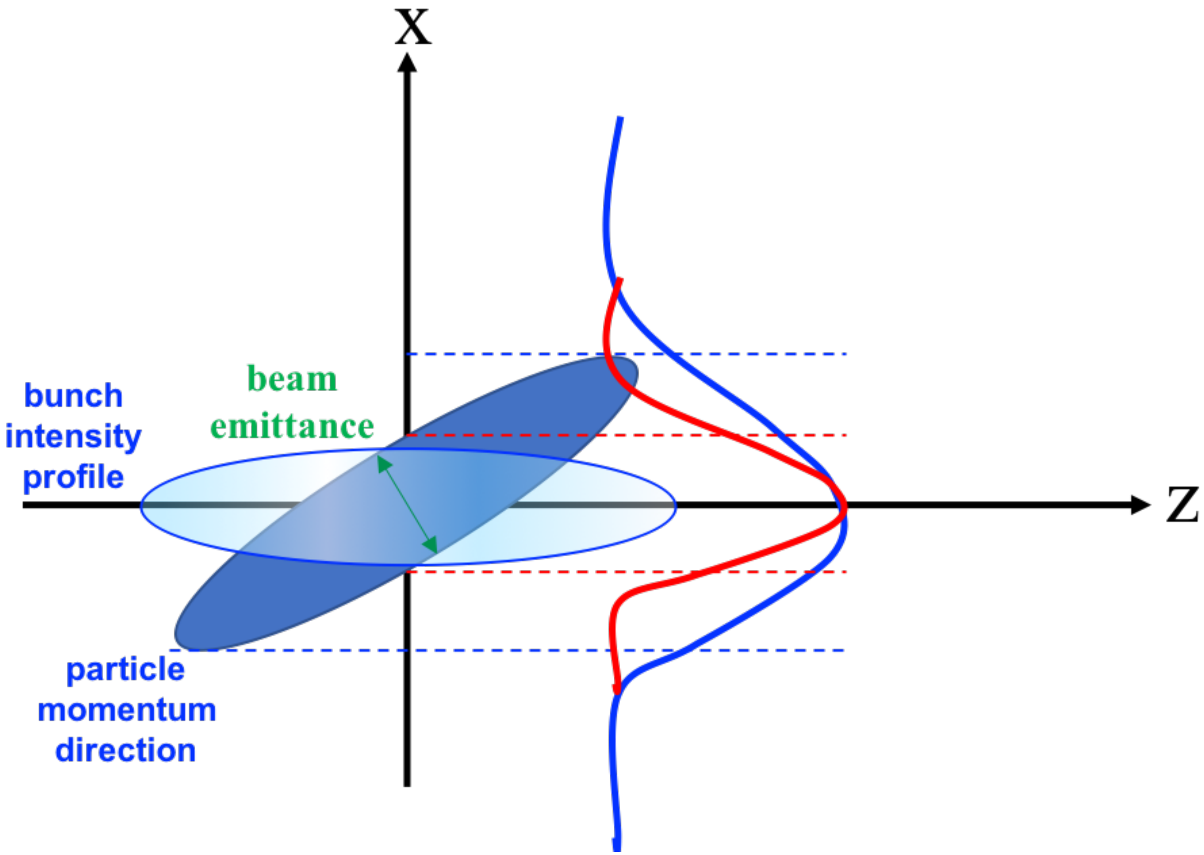

Short Diversion – Accelerator Jargon

- $\beta(z)$ is the RMS transverse beam size. $\boxed{\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}}$
  - $\sigma(z)$ is the Gaussian width of the beam, ε is the emittance.
- General rule of thumb is to keep Roman Pot sensors at $\sim 10\sigma$ distance from beam to limit exposure.

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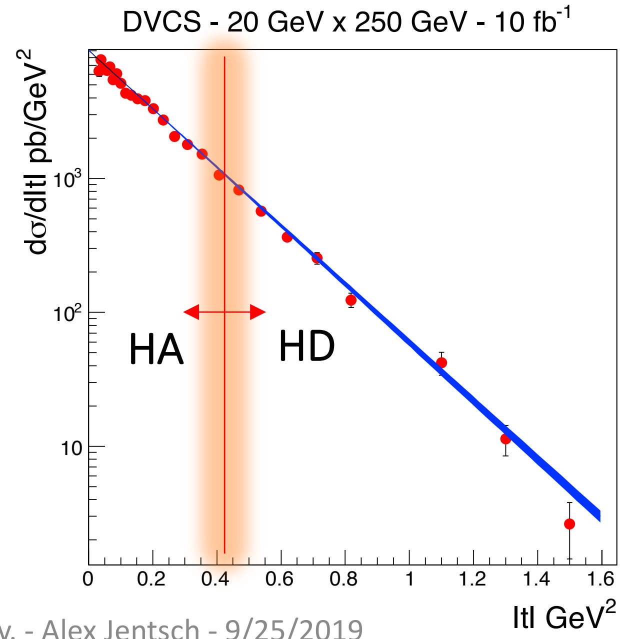
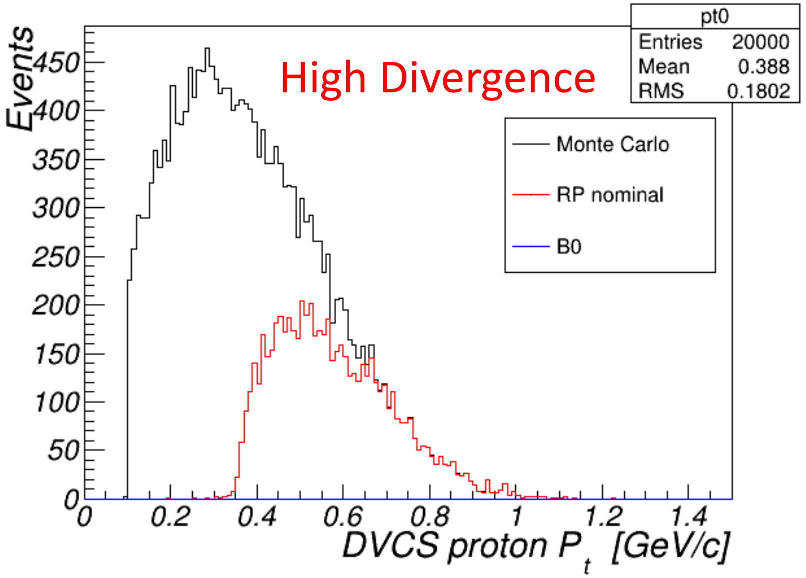
  - $\sigma(z)$ is the Gaussian width of the beam, ε is the emittance.
- General rule of thumb is to keep Roman Pot sensors at ~10σ distance from beam to limit exposure.
- **High divergence (HD)** – beta functions tuned such that small beam (σ) at IP (higher luminosity), at the cost of larger beam at Roman Pots.
- **High acceptance (HA)** – essentially the opposite configuration as the high divergence.

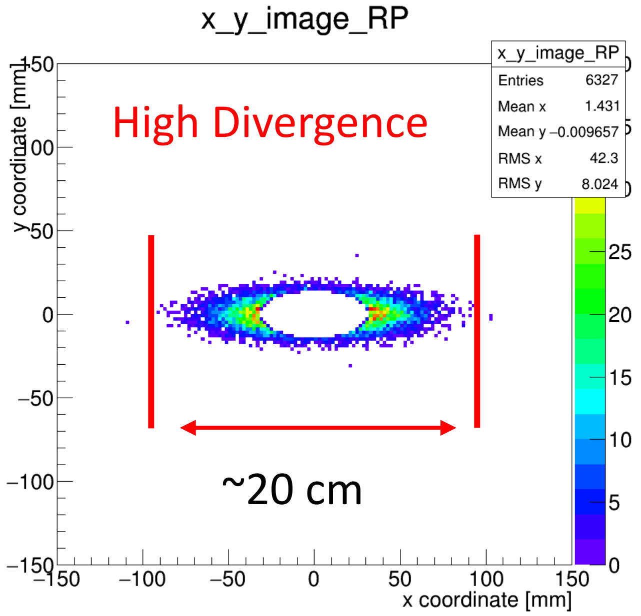
	18x275 GeV		10x100 GeV	
	HA	HD	HA	HD
RMS $\Delta\theta_H$, (urad)	65	133	180	203
RMS $\Delta\theta_V$, (urad)	277	251	243	227
Luminosity 10^{33} $cm^{-2}s^{-1}$	0.94	1.93	4.07	4.35

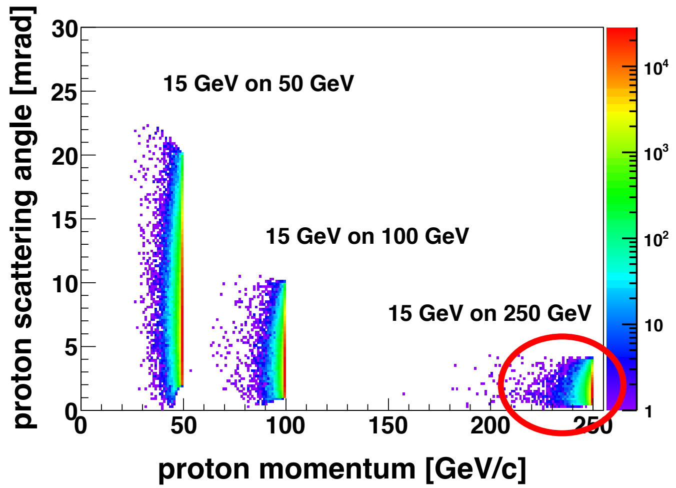


The different beam configurations yield different values of $\sigma(z)$ and change the safe operating distance of the Roman Pots!

275 GeV DVCS protons







The high divergence configuration severely reduces the low p_t acceptance.

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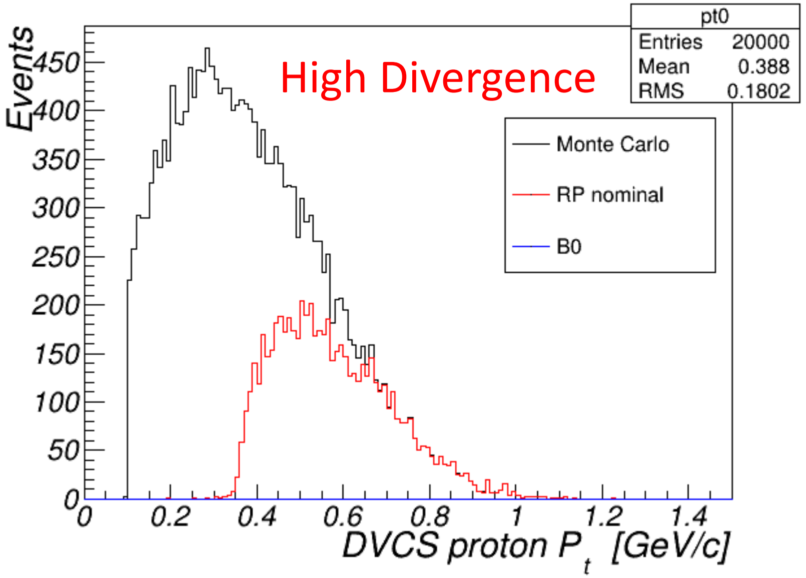

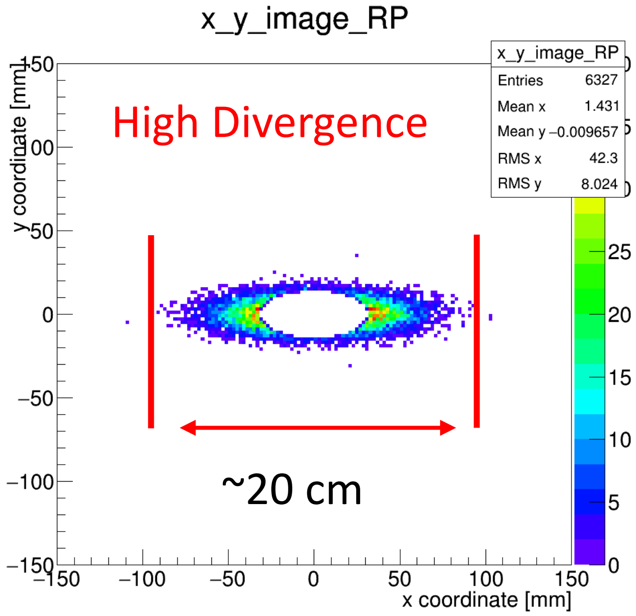

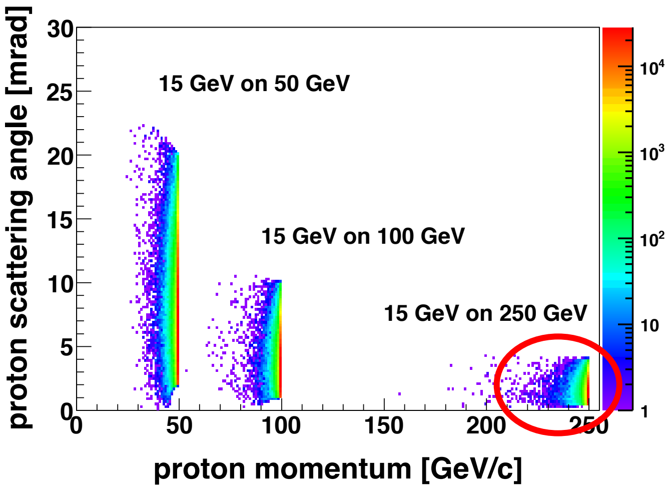

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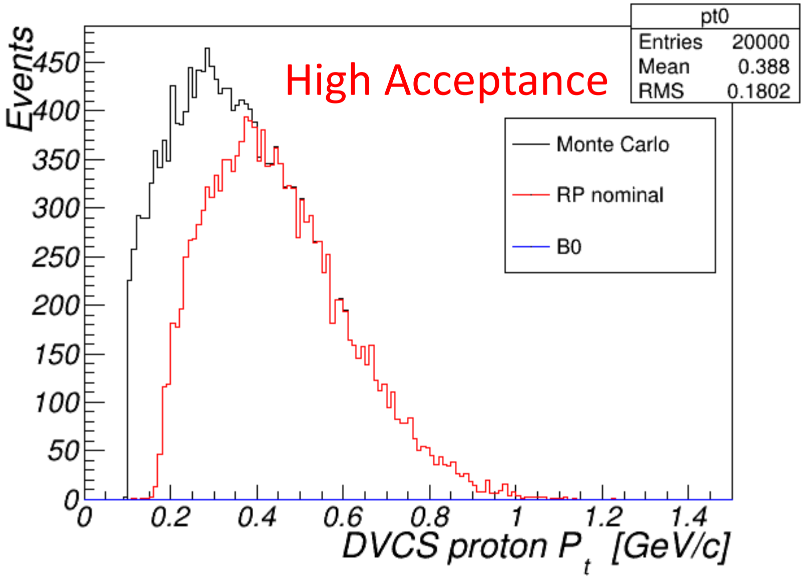
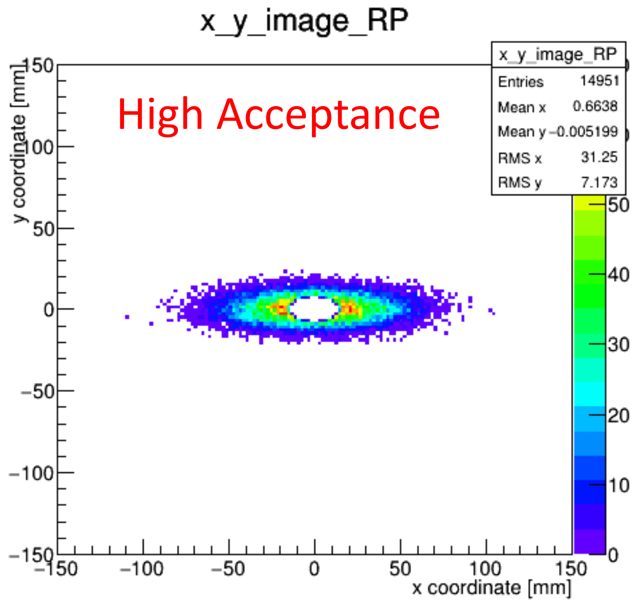
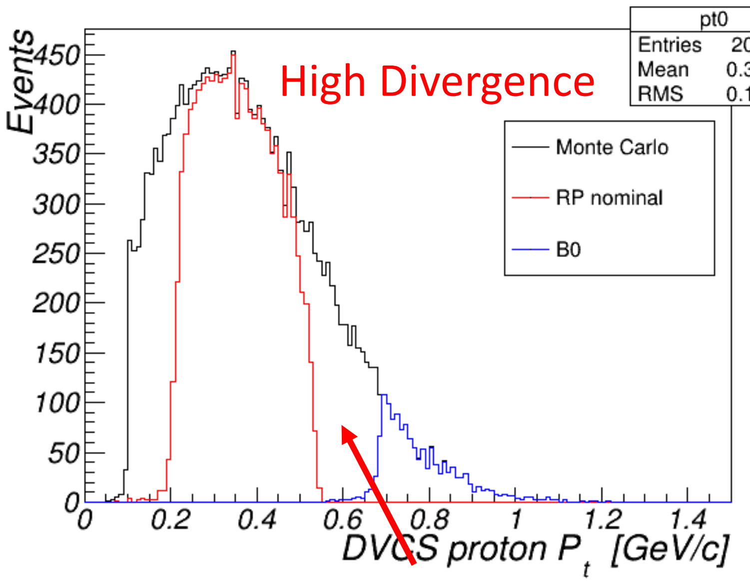


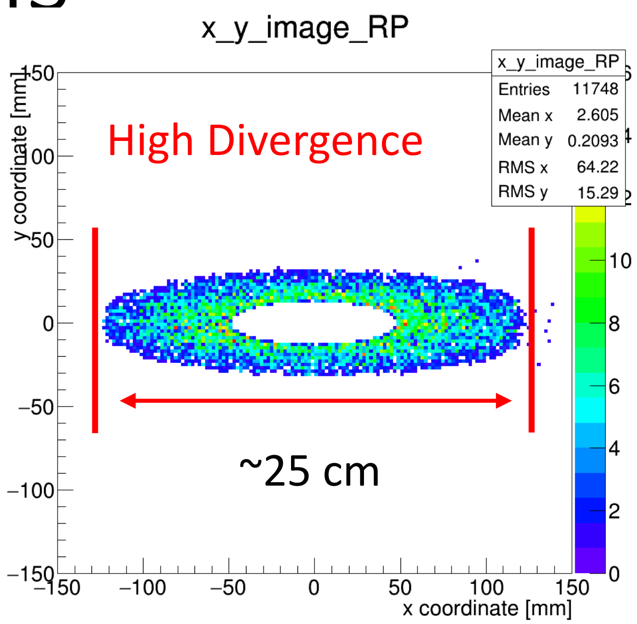


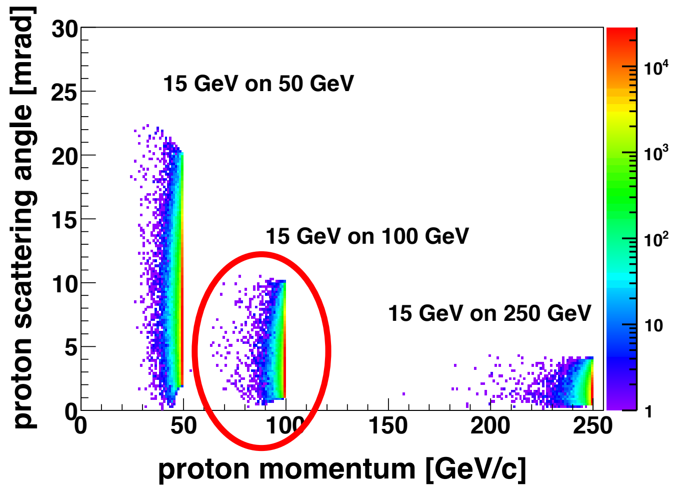
The high acceptance configuration improves the low p_t acceptance, but at the cost of a factor of 2 in luminosity.

100 GeV DVCS protons



Acceptance "grey" area.





The high divergence reduces low p_t acceptance. Magnet apertures restrict acceptance.

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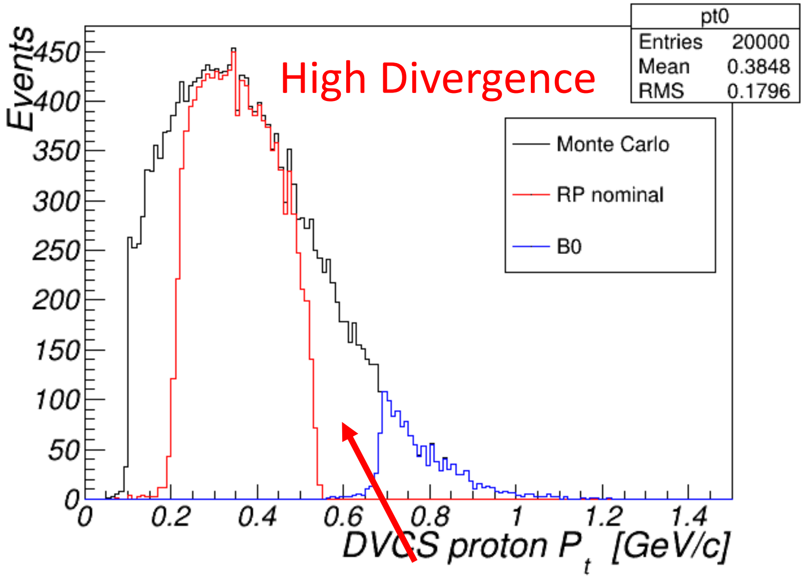

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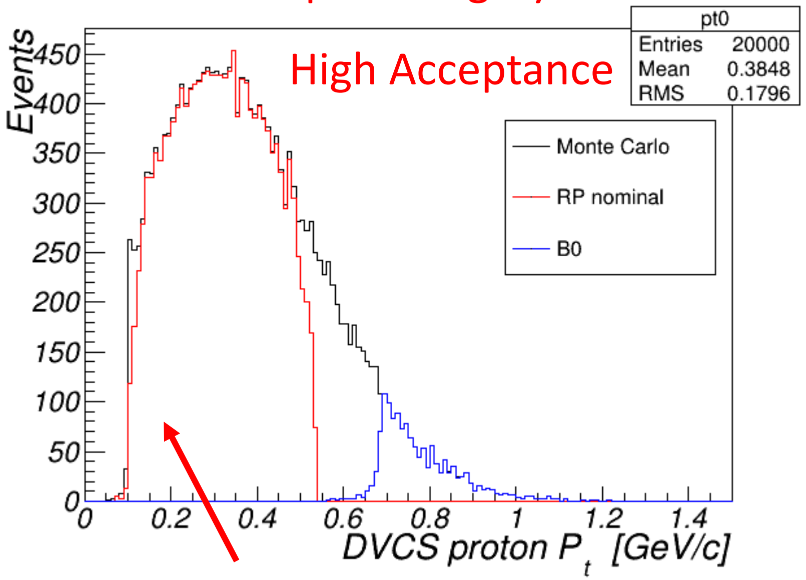
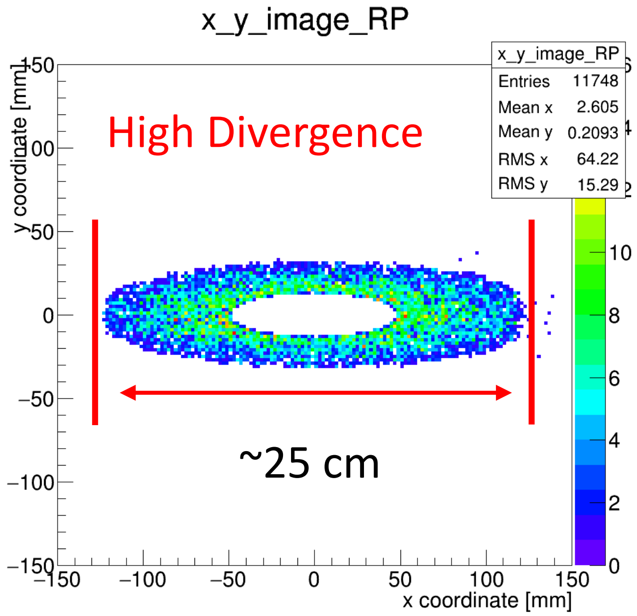
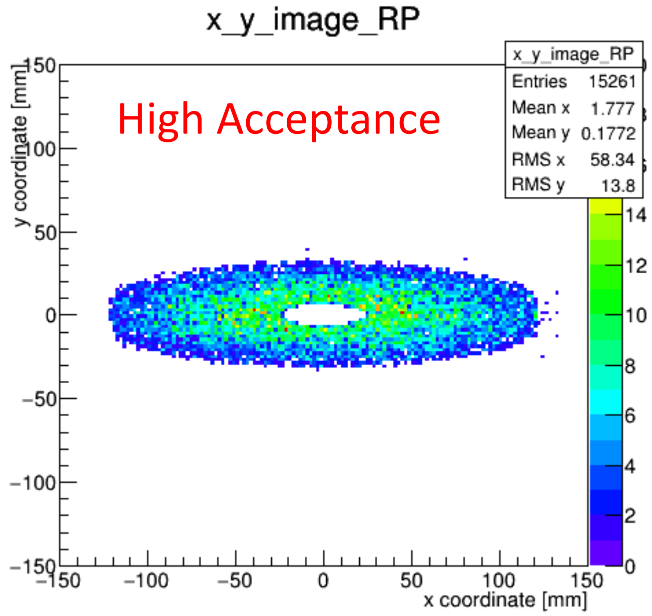
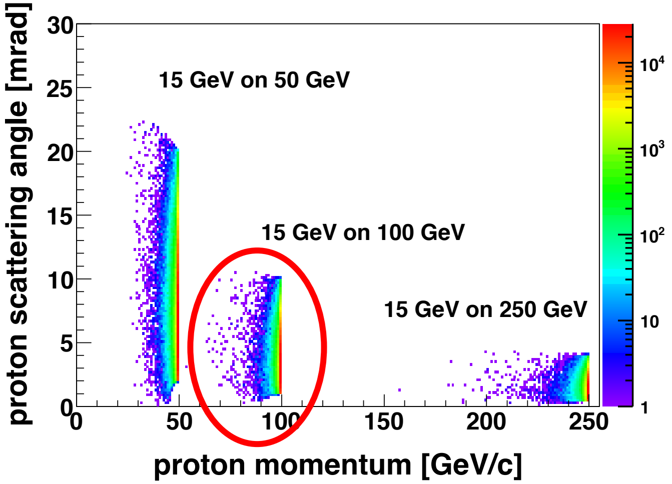


Improves low p_t acceptance.



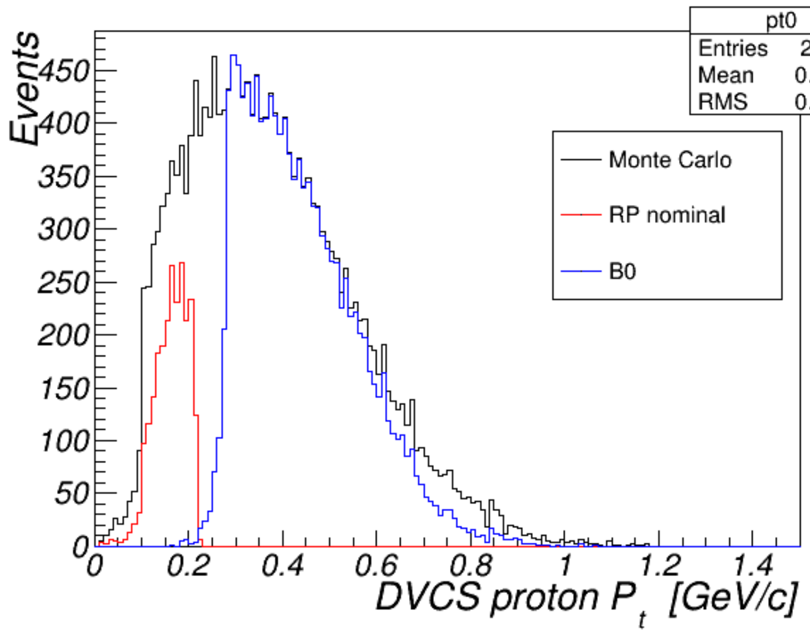


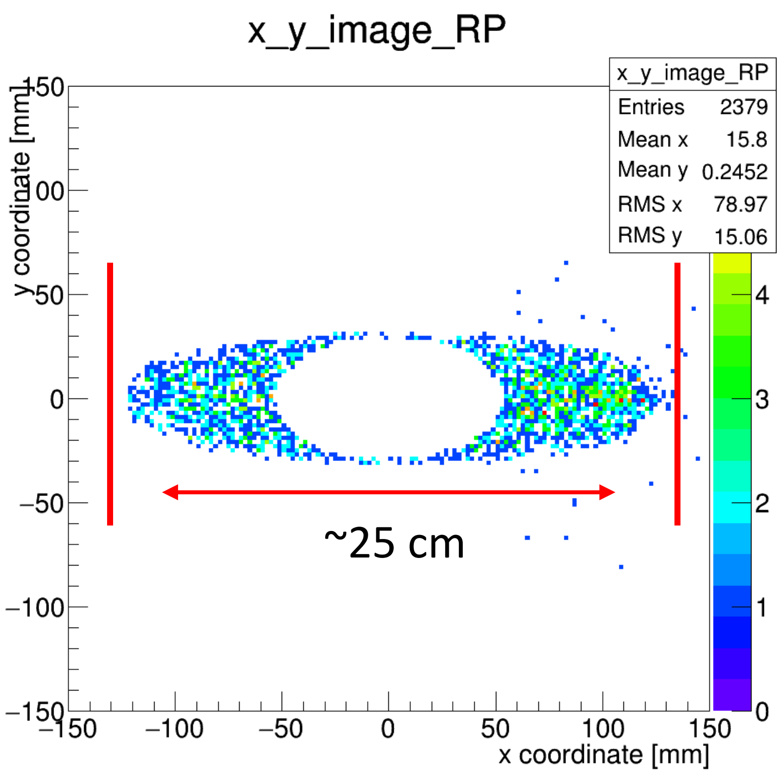


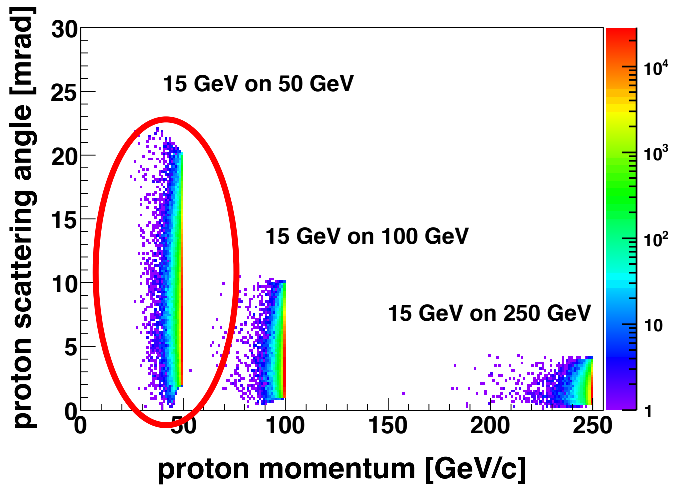
The high divergence reduces low p_t acceptance. Magnet apertures restrict acceptance.

The high acceptance configuration improves the low p_t acceptance, but at the cost of 10% in luminosity..

41 GeV DVCS protons







- Only one beam configuration for now.
- Acceptance gap still observed.
- Lower acceptance at high p_t.
- B0 plays largest role at this beam energy.

Momentum Resolution – 275 GeV

- Beam angular divergence -> $\Delta p_t \sim 40$ MeV/c – Worse-case

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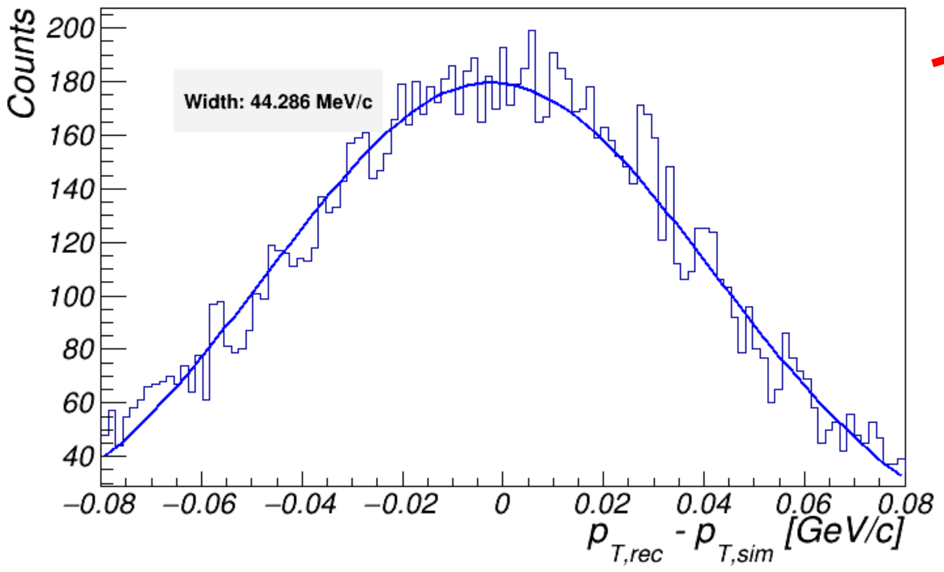
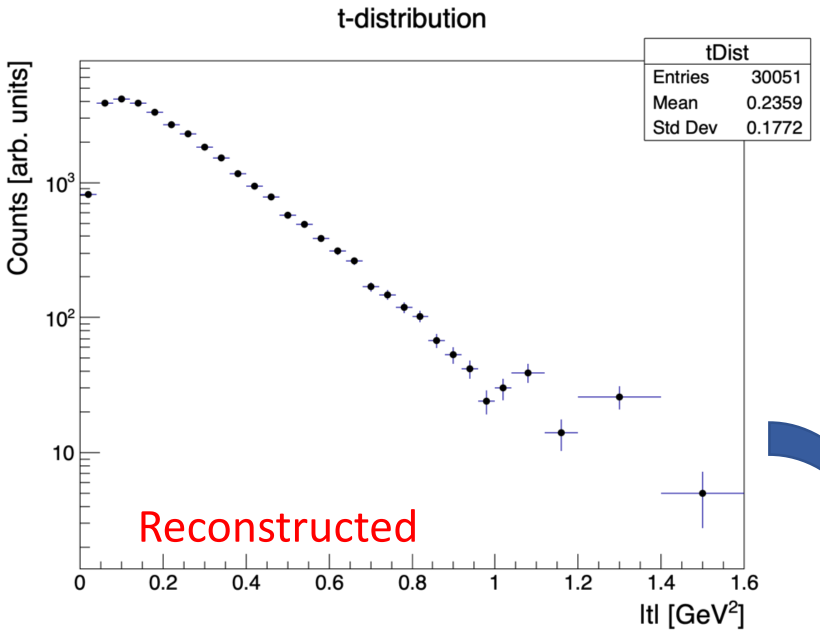
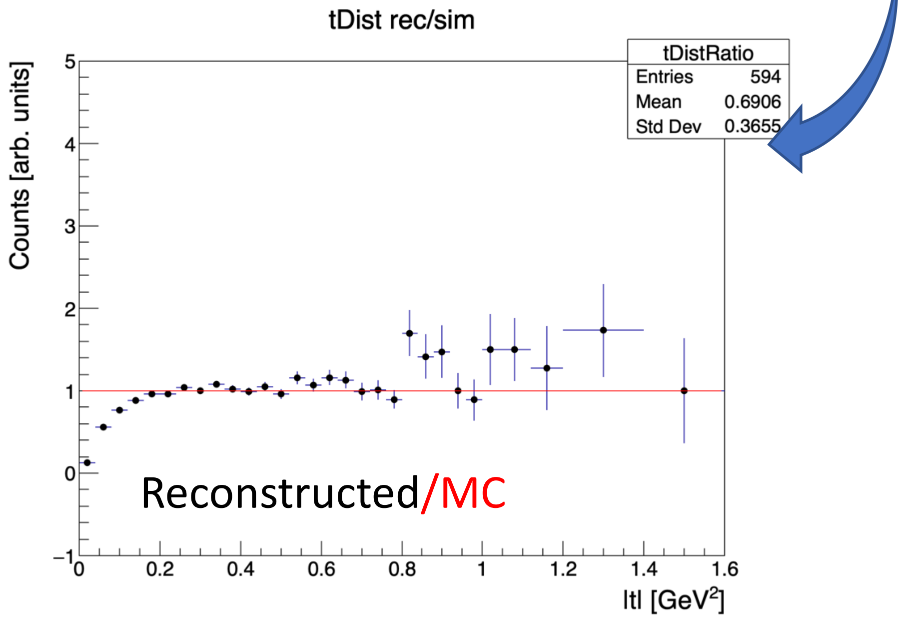
- **Total (worse-case): $\Delta p_t \sim$ 45 MeV/c.**







Momentum Resolution – 100 GeV

	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	22	N/A	N/A	10	9
B0 Δp_t [Mev/c]	25	17	38	N/A	20

- Total:
    - RP: $\Delta p_t \sim$ 23 MeV/c (worse case)
    - B0: $\Delta p_t \sim$ 26 MeV/c (20 um pixels)
- |t|-reconstruction requires combined Roman Pots and B0 information.
- Still allows reconstruction of |t|-dist since data points exist on both sides of gap.

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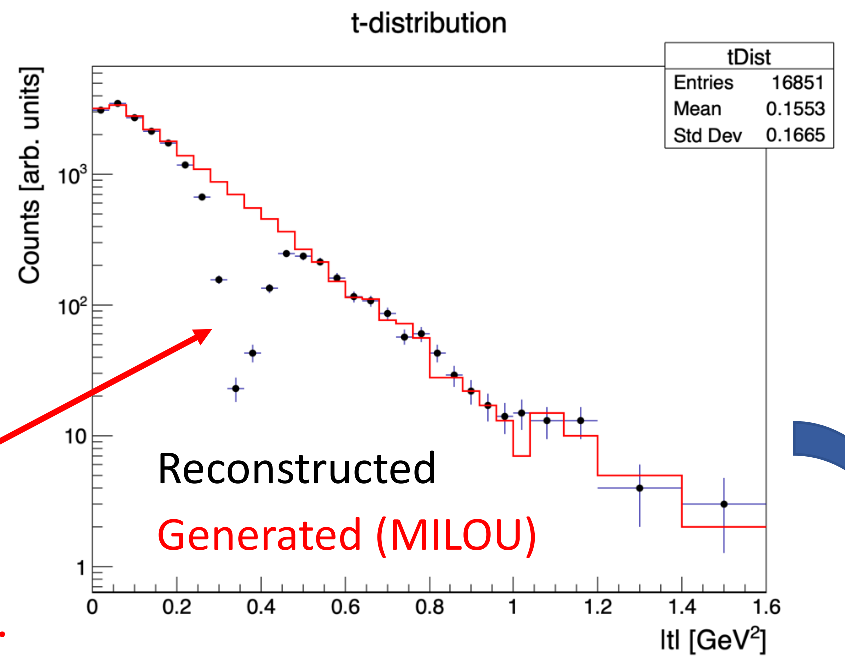

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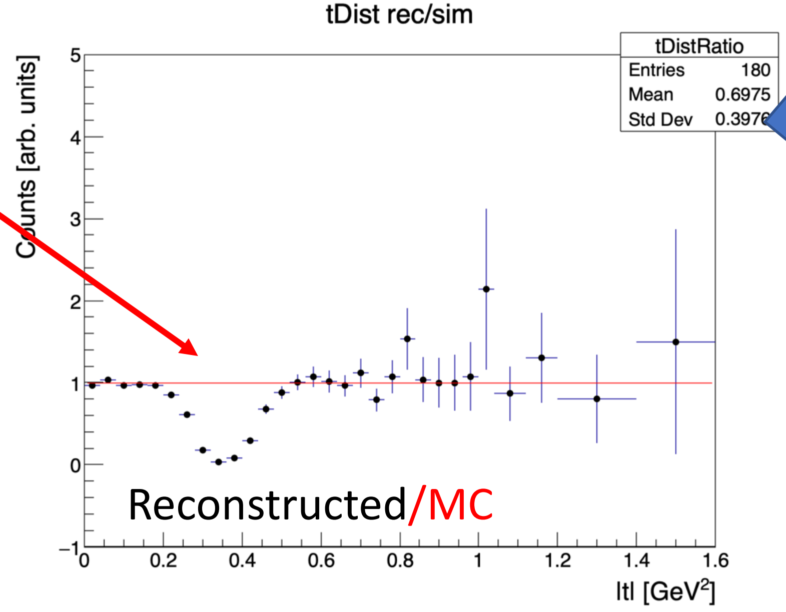


Momentum Resolution – 41 GeV

	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	14	N/A	N/A	10	10
B0 Δp_t [Mev/c]	17	13	25	N/A	10

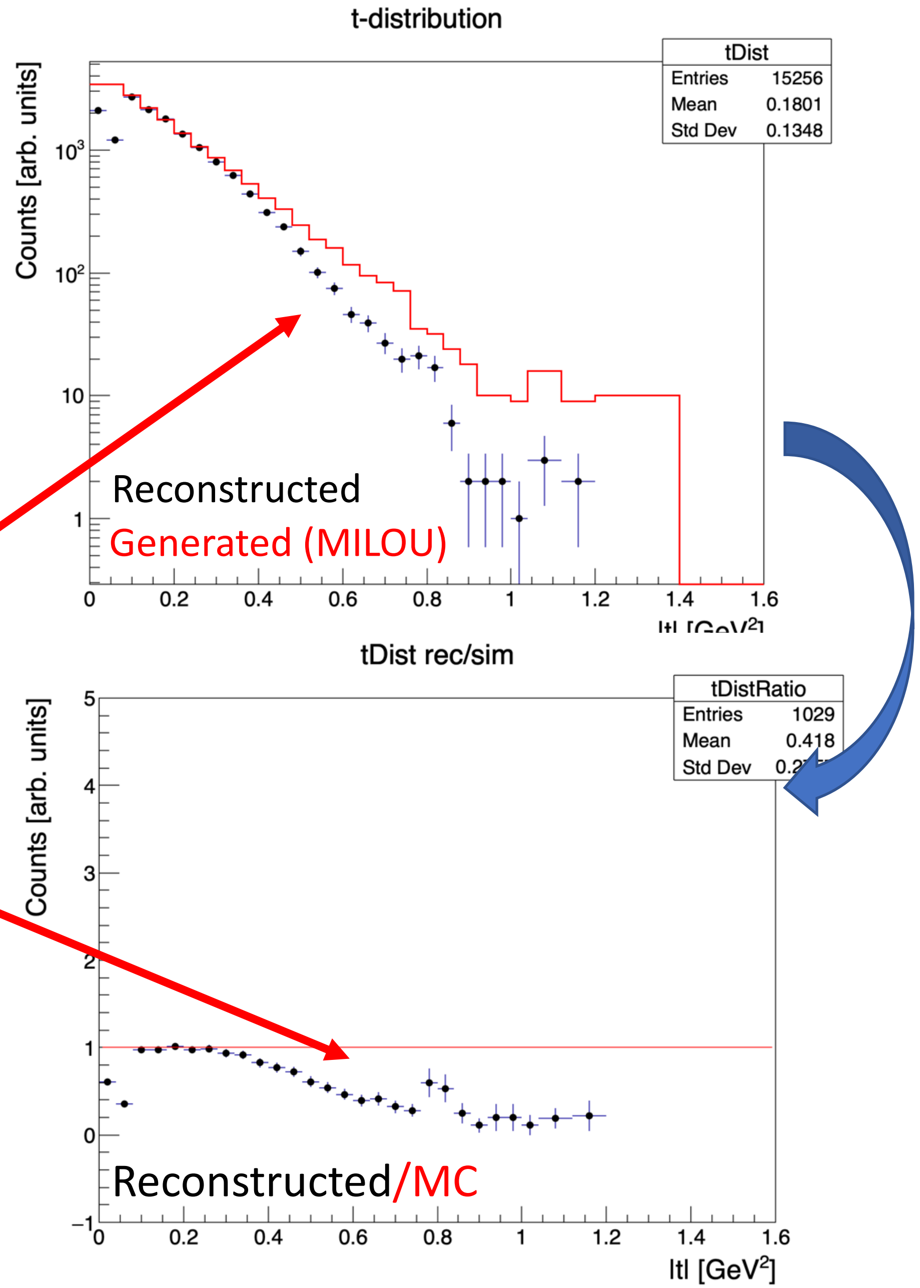
- Total:
  - RP: $\Delta p_t \sim$ 15 MeV/c (worse case)
  - B0: $\Delta p_t \sim$ 18 MeV/c (20um pixels)
- |t|-reconstruction requires B0 for majority of reconstruction.

Momentum Resolution – 41 GeV

	Ang Div.	20um pxl	55um pxl	500um pxl	Vtx Smear
Roman Pots Δp_t [MeV/c]	14	N/A	N/A	10	10
B0 Δp_t [Mev/c]	17	13	25	N/A	10

- Total:
  - RP: $\Delta p_t \sim 15$ MeV/c (worse case)
  - B0: $\Delta p_t \sim 18$ MeV/c (20um pixels)
- |t|-reconstruction requires B0 for majority of reconstruction.

Some acceptance issues. Optimization of B0 sensor layout in GEANT ongoing.



Notable Findings Thus Far

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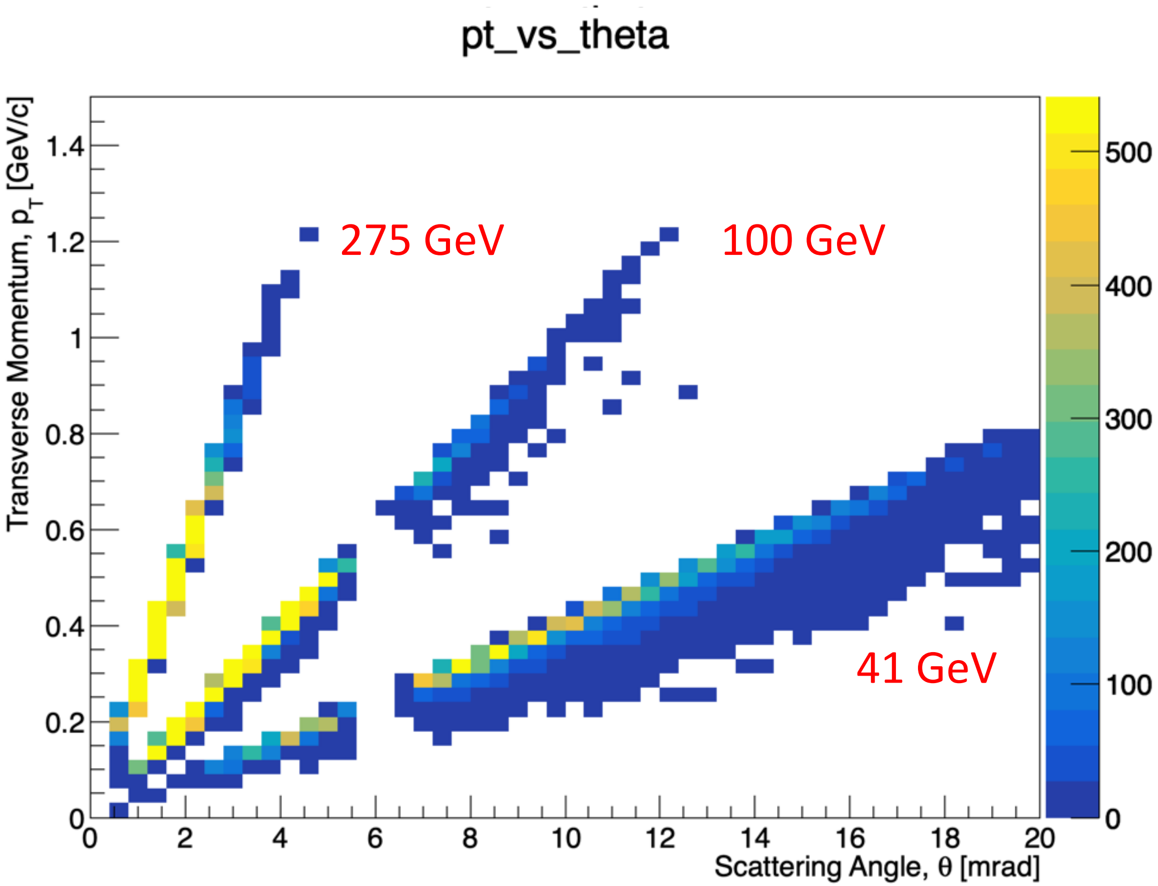
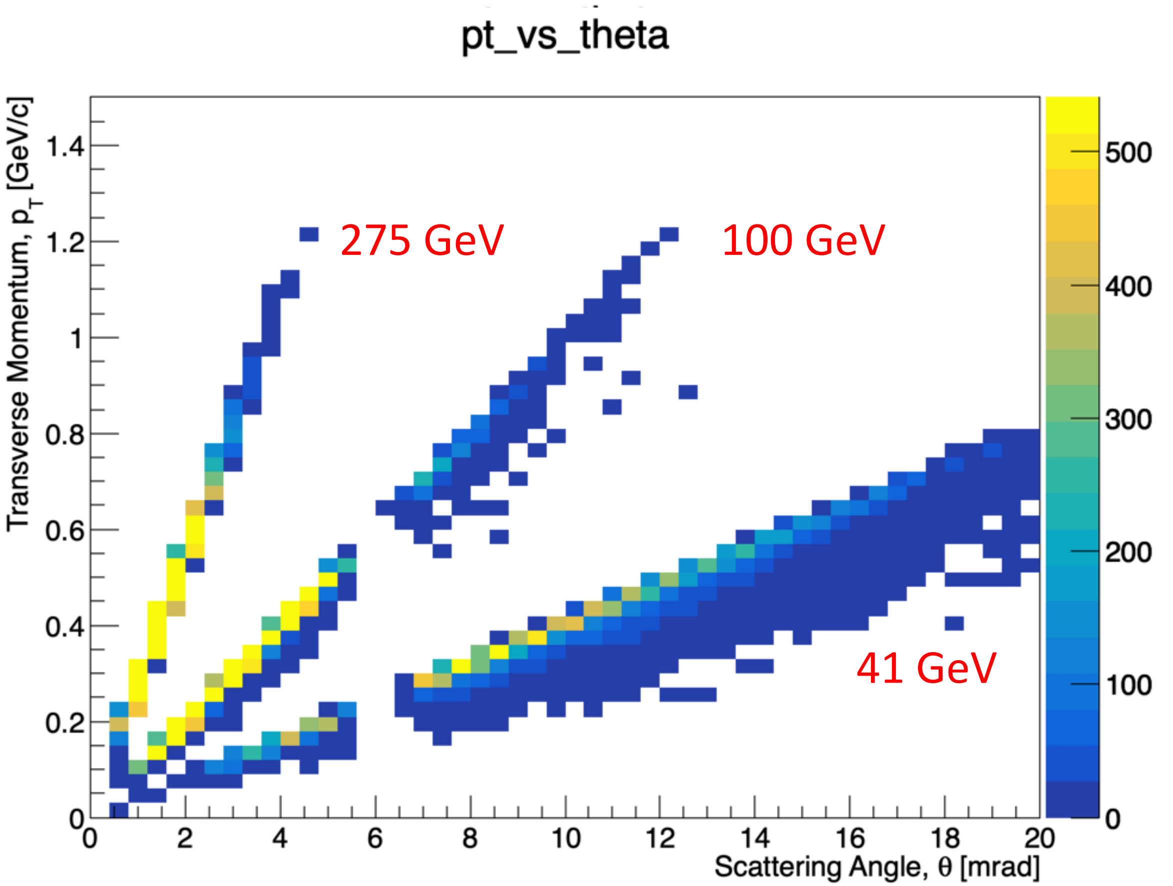


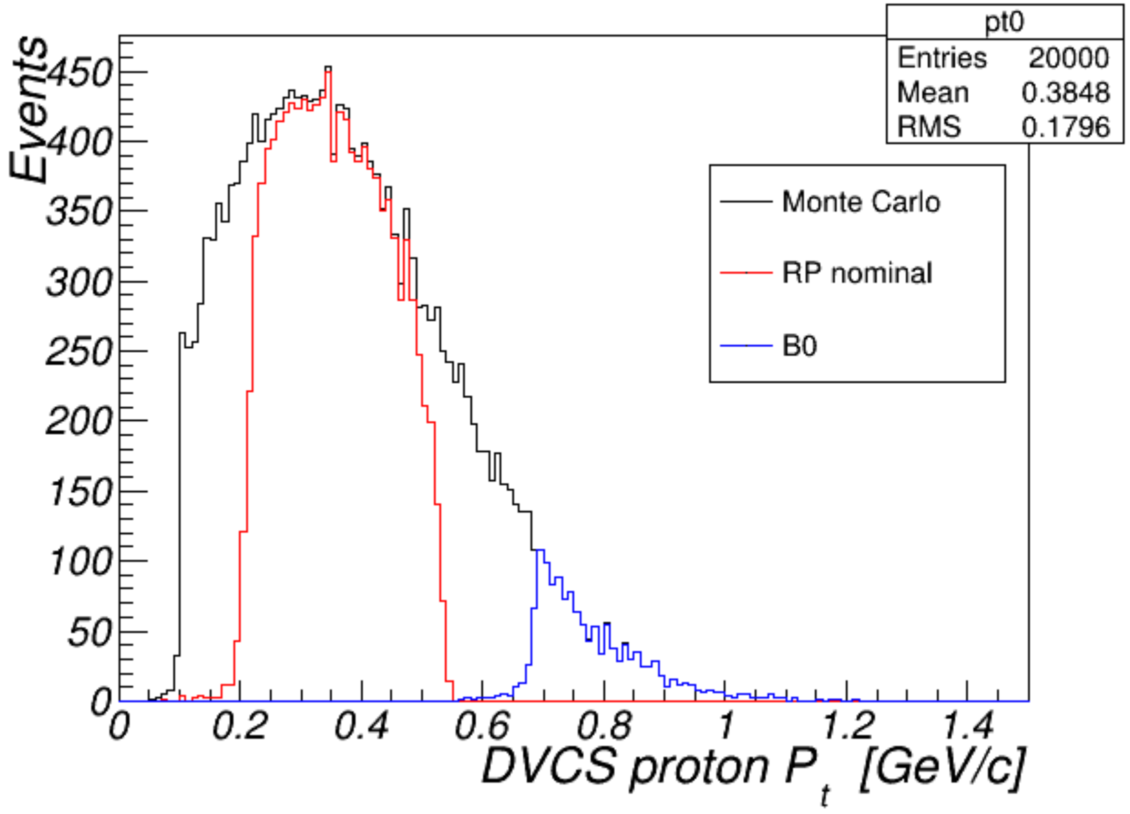
Notable Findings Thus Far

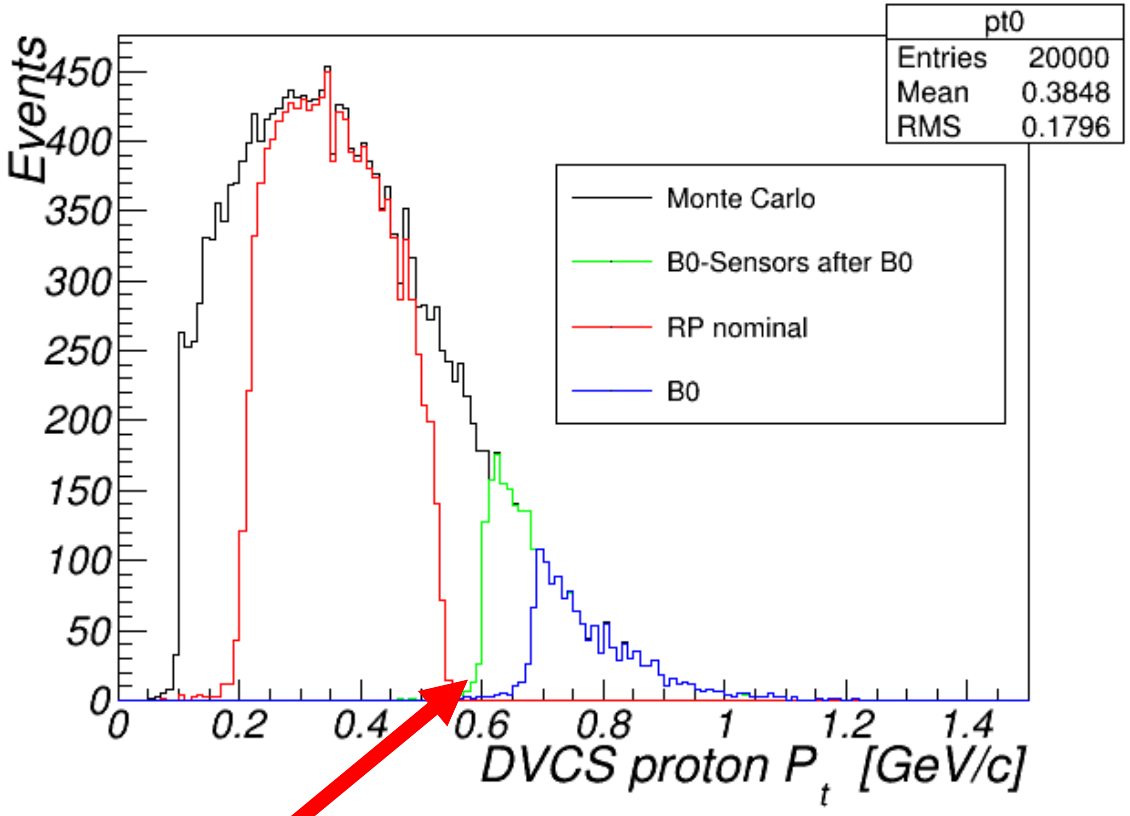
- The "high-acceptance" configuration crucial for low-p_t acceptance.
- There is a significant "grey" area of acceptance for both lower energy configurations.
  - Running simulations with potential additional sensors in the B0 section.
- Requirements for momentum resolution on B0 and RP sensors different.
  - B0 needs much smaller pixels.
- The total sensitive area needs to be roughly 20cm by 10cm to capture the full DVCS acceptance.



Filling the acceptance “grey” area.

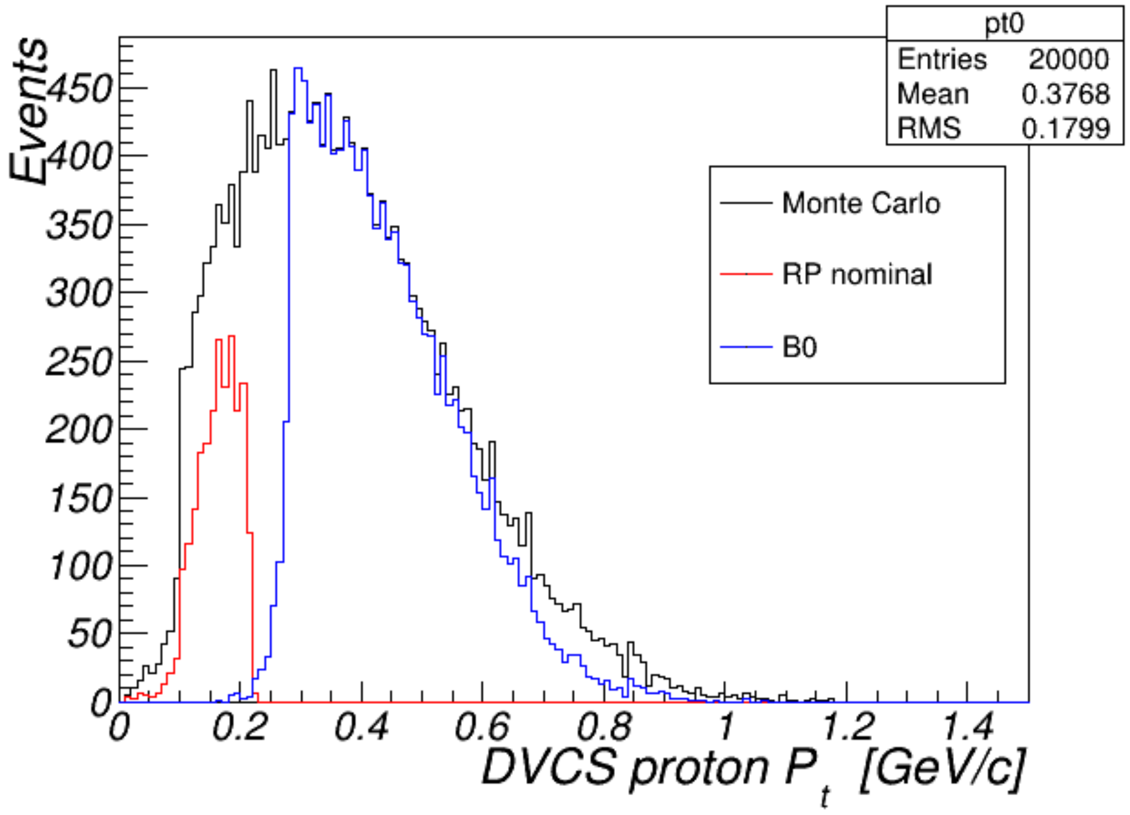
100 GeV DVCS protons – Supplemental Sensors

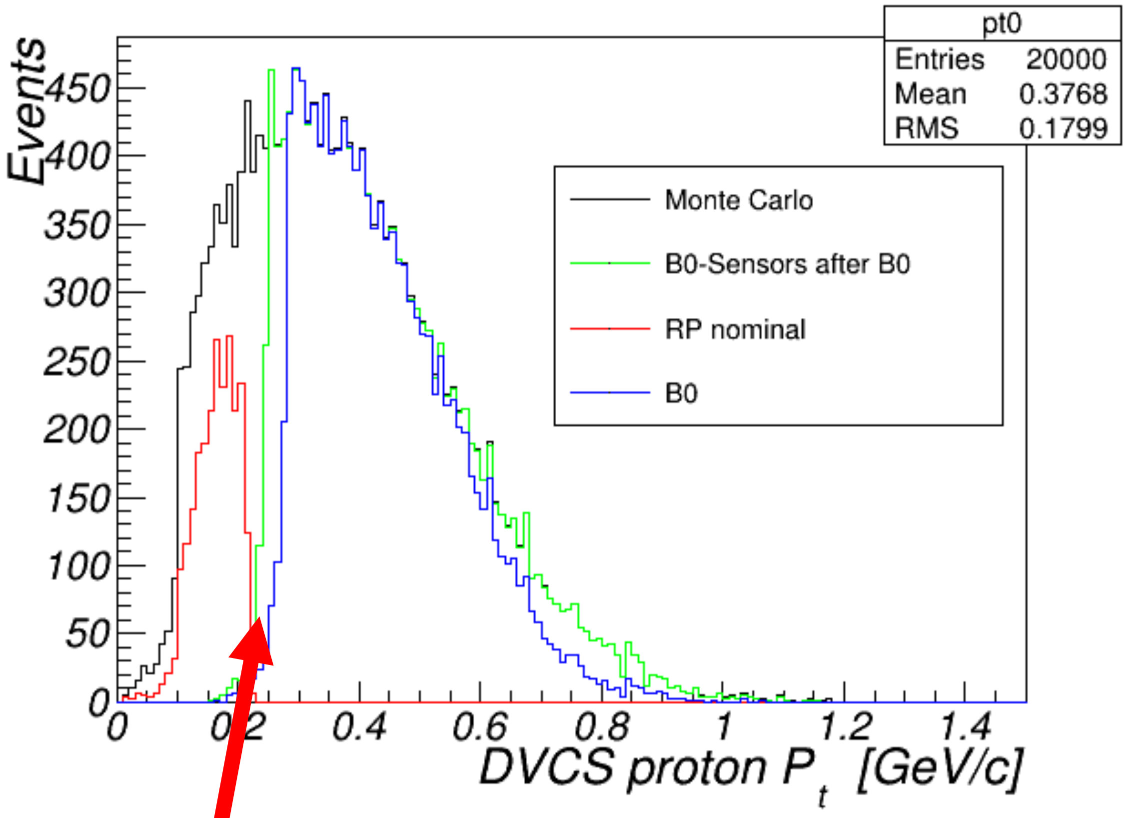




Fills about half of the missing acceptance.

41 GeV DVCS protons – Supplemental Sensors





Fills about half of the missing acceptance.

B0 detector + supplemental sensors

- There are practical (space) considerations for the supplemental sensors.
  - Working with CAD to understand what space we will actually have between dipoles.
- Preliminary studies of B0 resolution completed – much more sensitive to pixel size reconstruction of curved track.
  - Will need very small pixels (i.e. 20um x 20um) and a separate timing layer.
  - Need to understand required timing to apply vertex constraint.
- Will need to combine information from both B0 and Roman Pots to deliver full physics program.

Summary and Outlook

- Basic requirements for Roman Pots at eRHIC understood.
  - Acceptances studied – room for improvement.
  - Need very precise timing (20-30ps).
  - p_t resolution < 50 MeV/c for all energies.
- B0 + potential additional sensors required.
  - Covers lower proton beam energies.
  - Different requirements on sensors.
  - More detailed studies/optimization underway.
- R&D underway on the sensor design (timing, pixel pitch, etc.) and optimized layout of Roman Pots and B0 stations.
- Studies with e+A using BeAGLE underway.

Backup

Beam configurations

PARAMETERS	Proton
energy, GeV	275
rms_norm._emit.,h/v_um	4.6/0.74
rms_emittance,h/v_nm	**15.8/2.5**
emittance_y/emittance_x	0.159
beta,h/v_cm	**90/4.0**
IP_beam_size,h/v_um	**119/10.1**
IP_rms_ang_spread,h/v_urad	133/251

275 GeV – high divergence

PARAMETERS	Proton
energy, GeV	275
rms_norm._emit.,h/v_um	4.2/0.90
rms_emittance,h/v_nm	**14.4/3.1**
emittance_y/emittance_x	0.214
beta,h/v_cm	**340/4.0**
IP_beam_size,h/v_um	**221/11.1**
IP_rms_ang_spread,h/v_urad	65/277

275 GeV – high acceptance

PARAMETERS	Proton
energy, GeV	41
rms_norm._emit.,h/v_um	1.9/0.4
rms_emittance,h/v_nm	**43.6/10.3**
emittance_y/emittance_x	0.236
beta,h/v_cm	**90/7.1**
IP_beam_size,h/v_um	**198/27.1**
IP_rms_ang_spread,h/v_urad	220/380

41 GeV

PARAMETERS	Proton
energy, GeV	100
rms_norm._emit.,h/v_um	4.0/0.22
rms_emittance,h/v_nm	**37.1/2.1**
emittance_y/emittance_x	0.056
beta,h/v_cm	**90/4.0**
IP_beam_size,h/v_um	**183/9.1**
IP_rms_ang_spread,h/v_urad	203/227

100 GeV – high divergence

PARAMETERS	Proton
energy, GeV	100
rms_norm._emit.,h/v_um	3.5/0.25
rms_emittance,h/v_nm	**33.1/2.4**
emittance_y/emittance_x	0.071
beta,h/v_cm	**102/4.0**
IP_beam_size,h/v_um	**184/9.7**
IP_rms_ang_spread,h/v_urad	180/243

100 GeV – high acceptance